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ABSTRACT

The broad focus of this study was on the role students' existing conceptions play in the process of constructing and understanding mechanics concepts. The study was a naturalistic one, conducted over a number of years, at all grade levels, in one all-boys secondary school in Australia. In particular it was concerned with identifying and representing students' existing conceptions, and investigating aspects of the process of conceptual change in classroom learning. A restructuring of teaching approach preceded the investigations of conceptual change. Alternative conceptions were found to be common and complex. Subsequent conceptual change was often, but not universally, achieved. At the level of individual students, this change was idiosyncratic, complex, and often unpredictable. Some change resulted in more sophisticated alternative conceptions. Students were also found to have naive views of learning, and perceptions of the content of physics and how it should be learned which would hinder their learning. (Author/TW)

A longitudinal classroom study of mechanics concepts and conceptual change

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ABSTRACT

The broad focus of this study was on the role students' existing conceptions play in the process of constructing and understanding mechanics concepts. The study was a naturalistic one, conducted over a number of years, at all year levels, in the school in which the first author teaches physics. In particular it was concerned with identifying and representing students' existing conceptions, and investigating aspects of the process of conceptual change in classroom learning. A restructuring of teaching approach preceded the investigations of conceptual change. Alternative conceptions were found to be common and complex. Subsequent conceptual change was often, but not universally, achieved. At the level of individual students this change was idiosyncratic, complex, and often unpredictable. Some change resulted in more sophisticated alternative conceptions. Students were also found to have naive views of learning, and perceptions of the content of physics and how it should be learned which would hinder their learning. The various investigations in the study also promoted considerable conceptual change in the researchers. These are commented on in the paper.

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INTRODUCTION

The prime motivation for this study was to better understand conceptual learning of physics in the senior secondary school. The study derives from the burgeoning alternative conceptions literature-that is, from the consistent findings of student ideas and beliefs about the phenomena and concepts of science which can be alternative to the tenets of science (e.g. Driver et al., 1985; Hashweh, 1988; McDermott, 1984; Osborne & Freyberg, 1985; West & Pines, 1985).

The series of investigations undertaken in this study also reflects conceptual change in the authors, in particular the first author. This issue may seem tangential, but has been most significant in the evolution of this study. It is briefly discussed below as part of the context of the study.

The bulk of the work being reported in this paper has its origins in two related theoretical positions. The first is the generative model of learning (Wittrock, 1974). Subsequent elaboration of this theory in the context of science learning (Osborne & Wittrock, 1983, 1985) combines research on the relationships between sensed experiences, short-term and long-term memory, and alternative conceptions held by science students. The generative model takes a constructivist view of learning. This view of learning holds that learners construct their own meanings for experiences (including the experiences of formal education); that this construction of meaning is a continuous and active process which includes learner evaluation of the changing constructions; and that the nature of the personally constructed meaning is affected by the "conceptions, purposes and motivations" (Driver & Bell, 1986; p.444) which the learner brings to an experience. This latter point is a significant one for the present study, as is illustrated by an

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example of learning about falling bodies in science or physics classes. Many students come to such learning with the belief that heavier objects fall faster than lighter objects. When presented with the science generalization that acceleration in a gravity field is independent of weight, some of these students may conclude that heavy and light objects have the same weight (Gunstone, Champagne & Klopfer, 1981, p.28). Such a construction allows the existing belief to be unaffected even though the new idea has been accommodated, and illustrates well the impact it is possible for existing conceptions to have on new learning.

The second theoretical position on which the present study draws is also constructivist in nature. This is Posner et al.'s (1982) view of conceptual change in which they argue that dissatisfaction with an existing concept is only the first step in conceptual change. In addition the new conception must be, to the learner, intelligible, plausible, and fruitful. Having a new conception seem fruitful (i.e. offer a more valuable way of thinking about whatever is being considered) is very difficult. Consider again the example above of the meanings constructed by some students for falling bodies, acceleration due to gravity, and weight. Students who construct the view that heavy and light objects have the same weight have a set of ideas which can seem cohesive and internally logical. To rethink and restructure these ideas will involve considerable intellectual effort. Unless this effort appears to them to be fruitful it is unlikely that the process of restructuring will even begin. They may well give the answer they know is expected on tests, but retain the alternative conception as a way of interpreting the world.

These two constructivist positions - the generative learning model and the intelligibleplausible/fruitful perspective on change - underlie the investigations of conceptions and conceptual change in this study.

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PURPOSES OF THE STUDY

The study had three broad thrusts: to examine students' existing conceptions in some areas of mechanics (with a particular focus on gravity); to investigate the process of conceptual change; to probe aspects of any relationships between existing conceptions and conceptual change. These purposes are elaborated in the description of the collection of data below.

CONTEXT OF THE STUDY

This we briefly describe from two perspectives: the physical setting in which the study took place, and the intellectual context of the study. By the latter we mean the ways in which the conceptions of the researchers changed through the period of the research. First the physical setting is considered.

The study took place in a grade 7 - 12, all-boys secondary school in which the first author teaches physics. This author is referred to below as teacher/researcher. The education system in which the school is located has all students in grades 7 - 10 studying general or integrated science, and some students electing to study a two year specialist physics course in grades 11 and 12.

Data were collected over a five year period by the teacher/researcher. During this time the focus of these data shifted in ways which reflected the conceptual changes in the first author's considerations of the learning of physics. These changes came from reflection on data (both from the separate investigations in this study and from published research) and interactions with other researchers. The details of the evolving thrusts of data collection are given below. In essence data collection began with probing to determine if alternative conceptions existed in science (years 7 - 10) students in the school, then moved to a consideration of students entering year 11 in terms of alternative conceptions, then to a probing to determine if alternative conceptions existed among students

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during the study of physics in years 11 and 12, and beyond. These physics classes were taught by the teacher/researcher, an experienced teacher with a consistent record of producing high achievers at the end of year 12 physics. The finding of alternative conceptions among his year 11 and 12 students, even after his (at that time conventional) teaching caused the teacher/researcher to reconsider many of his conceptions of physics teaching and learning. As a consequence, this study moved into a second phase which focussed on the effects of restructuring teaching around Posner et al.'s descriptions of conceptual change.

We have three intertwined reasons for this brief description of the intellectual evolution of the study and for returning to this issue later in the paper. Firstly it explains why the sequence of investigations was conducted. Secondly it illustrates the importance of researchers considering their own conceptual change, and the vital role of fruitfulness in that change (Gunstone & Northfield, 1986). In this case fruitfulness to the teacher/researcher became student understanding and acceptance of the perspectives of physics, rather than the ability to solve standard physics problems. Thirdly it demonstrates the potential power of the two methodological perspectives which came to strongly influence the approach to the research. We turn to these perspectives now.

THE NATURE OF THE STUDY

The approach to this naturalistic, classroom-based study was substantially influenced by two methodological perspectives: the teacher-as-researcher (Stenhouse, 1975) and the reflective practioner (Schon, 1983).

Both of these perspectives support the position that research on school learning should be rooted in normal classrooms, thereby providing the opportunity to achieve unity between theory and practice by advancing both. Stenhouse (1975) argues that an action-research framework can be successfully employed by teachers wishing to initiate

research, and that this framework not only facilitates the discovery of hypotheses whose testing can lead to the improvement of practice, but it also serves as an alternative route for the generation of theory. His position is well summarized by his statement that "(i)t is teachers who, in the end, will change the world of the school by understanding it" (Rudduck & Hopkins, 1985, p.vii).

The criticism of conventional research paradigms, such as psychometrically based statistical studies, which is implied by Stenhouse's position is also argued by Schon (1983). Schon suggests that conventional paradigms cannot solve problems in complex fields such as education because these paradigms cannot account for, or even understand, competent practice. He suggets an alternative paradigm based on an epistemology of practice - the approach of the reflective practitioner. When a unique problem situation is encountered in practice, it is recognized by the reflective practitioner as resembling another more familiar problem. In a process similar to that of scientific theory construction a "generative metaphor" is constructed from the reflective practitioner's (teacher's) previous knowledge and experience, knowledge and experience codified as repertoires of exemplars, overarching theories, etc. This framing of the problem leads to action research which can generate a variety of outcomes, expected and unexpected. After analyzing and reflecting on these outcomes the research either loops back for further inquiry, or terminates.

There appear to be three broad advantages in such an approach. Firstly, the means and ends of the inquiry are framed interdependently during the process of conducting an appropriate "reality" for that particular problem. This contrasts with the separation of means and ends, and the need to reach fixed objectives, in more conventional approaches to research. Secondly, practice is an integral part of research. This contrasts with the more usual separation of research ...

and practice in which practice is seen only as an application of research based theories. Thirdly, understanding is often dramatically enhanced by praxis. This contrasts with the more usual research approach which separates the knowing from the doing, so that action is only an implementation (and sometimes a test) of previous decisions.

It is important to note that both of these positions (Stenhouse and Schon) are consistent witn a constructivist view of learning in that both emphasize the importance of constructing a reality from the research situation. The nature of this reality seen by both writers as a function of the individual who constructs it; again a clearly constructivist perspective.

These methodological perspectives, with concern for teacher-as-researcher and the power of reflection on practice as a generator of both questions and hypotheses, add further detail to the brief description already given of conceptual change in the first researcher. Greater detail of these changes, and the practical effects of the two methodological perspectives, are implicit in the descriptions of the nature of data collected in the study.

THE COLLECTION OF DATA

As already suggested the study had two distinct phases - probing existing conceptions and probing conceptual change. These we consider separately, and further divide into the distinct parts of each phase. The order shown for these parts and phases is the same as the temporal sequence of data collection and, again as already suggested, reflects researcher conceptual change. As well as indicating the specific purpose and form of data collection for each part, we also indicate how each part contributed to the researcher conceptual change.

In discussing student conceptions in this study, we sometimes use the term "cognitive structure". This reflects a concern with the broader structure of ideas and beliefs held by students, in particular with issues such as consistency across contexts of the conceptions of students.

Phase One of the Study

Phase One of the study involved eliciting, identifying and representing the conceptions of students at various levels of the secondary school in which the teacher/researcher is a staff member. The content focus of these investigations was mechanics, with particular concern with conceptions relevant to gravity. Phase One contained four distinct parts. These are now considered in sequence.

Part I

In this first investigation a series of sets of written questions designed to probe conceptions were given to groups from years 7, 8, 9 and 10. These were described to students as "science learning surveys". A total of 18 of these surveys was given, some to more than one grade level. Each was administered by the teacher/researcher to intact classes in scheduled science lessons. Many of the questions included in the surveys were taken from existing research studies, while some were developed by the teacher/researcher as a result of reading published research. The substantial quantity of data which was generated was represented on a matrix developed for this purpose (described below in "Analysis of Data"). This representation allowed for analysis in terms of frequency of particular responses and consistency across contexts of conceptions held by a given individual.

The purpose underlying the Part I investigation was to explore the extent to which published research results could be held to apply to students in this particular school and, by inference, students in this educational system. The finding that both the nature and frequency of alternative conceptions was broadly similar to the situation described in the literature led to Part II of this phase of the study.

Part II

Reflection on the raw data and analyses of the data from Part

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I resulted in an investigation of the validity of the patterns emerging from the science learning surveys. Individual interviews were conducted with year 9 (n = 4) and year 10 (n = 12) students. These probed more deeply conceptions in some of the areas addressed by the surveys. The interviews were transcribed and analyzed in the same way as the survey data.

The interviews gave no reason to doubt the validity of Part I data. This then led to consideration of alternative conceptions in physics students (years 11 and 12), and those beginning year 11 physics.

Part III

This part of Phase One focussed on senior physics students from two perspectives.

Perspective (a): Conceptions of year 10 students were assessed (towards the end of the school year), again via written responses. When, in the next year, these students began year 11 study, two groups were created: those studying physics (n = 43) and those not studying physics (n = 54). The two groups were then compared in terms of nature and frequency of alternative conceptions found in the year 10 probing. The achievement scores at the end of year 10 science of the two groups were also compared.

Perspective (b): The conceptions of year 11 (n = 47) and year 12 (n = 32) physics students being taught by the teacher/researcher were probed. This probing was in the area of air flow and Bernoulli effects, an unfamiliar context in which the concepts of mechanics could be applied. The same probes were used with both year levels. The probes used the Demonstrate - Observe - Explain strategy (Champagne, Klopfer & Anderson, 1980; Gunstone & White, 1981), a strategy we now prefer to call Predict - Observe - Explain (POE). The data from these probes was compared by year level, and, for each year level, with scores on the standard forms of achievement tests used to grade each of these two groups.

The conceptions of students in both of the Part III investigations were again represented on the matrix described below, and from this representation analyses were made. The common presence of alternative conceptions among these physics students motivated a final probing for alternative conceptions - Part IV of Phase One.

Part IV

A graduate of year 12 physics (and from the teacher/researcher's classes) was interviewed at length to probe his conceptions of a number of gravity related phenomena. This student had gained 99% on the statewide, norm-referenced year 12 physics exam undertaken by 5500 students. He was clearly a very high achieving student. Once again alternative conceptions were found.

Phase Two of the Study

The sequence of Phase One investigations then led to Phase Two, a concern for probing the process of conceptual change and possible causes of any change. This came from the consistent demonstration in Phase One of a lack of conceptual change, particularly in years 11 and 12. This was, at the time, of major significance to the conceptual change of the teacher/researcher as the physics students in question were (as groups) quite highly successful in terms of achievement on conventional physics assessment items.

This resulted in a substantial change in one aspect of context for Phase Two. The teacher/researcher, who was teaching physics to all students involved in this second phase, radically restructured his classroom practice in order to attempt to promote greater conceptual change. This restructuring was based on the pedagogical suggestions given by Posner et al. (1982, pp.223-6) in their discussion of the conceptual change model described earlier in this paper. These suggestions and existing probes of student ideas were considered in developing a series of demonstrations, questions, videotapes, etc., which were specifically designed to promote discussion about, and

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challenge, alternative conceptions. The construction of these pedagogical tools, whose use was the major component of classroom teaching in Phase Two, was directly influenced by the Phase One data where specific alternative conceptions had been identified in students' existing cognitive structures.

Phase Two also can be seen in four parts, although the last three of these are less distinct than was the case for Phase One. Analysis of data from parts I - III was again via use of the matrix described below.

Part I

The same 15 written questions probing conceptions of gravity were given to year 11 (n = 48) and year 12 (n = 26) at the commencement of a particular school year. Reasons for answers were asked for. Hence this was a quasi-longitudinal study. Questions on the study were designed to reflect instruction received by the year 12 group in their year 11 study.

Part II

Here conceptual change in mechanics (including gravity) was considered for two successive groups (n = 20 and n = 24) through years 11 and 12 physics, again by using written responses. Each group was a single class, with data from those who completed both years being considered here. For each group the same set of questions was answered (with reasons) near the beginning, about the middle, and near the end of the two years of physics study. The first of the two groups answered a set of 6 questions, 4 of which are those detailed in Gunstone (1987). The subsequent group answered a different set of 17 questions at the same 3 times. This different set explored a wider range of concepts.

Part III

A more detailed probing of any conceptual change was undertaken by repeated interviewing of seven students from the second group of the Part II cohort. These seven were selected at the beginning of

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year 11, on the basis of year 10 achievement, with the intent of gaining a distribution of likely learning outcomes. That is, the seven were intended to represent the range of likely difficulties with conceptual learning, motivation to study physics, and so on. Each interview lasted approximately 90 minutes, and focussed on the questions used in Part II of Phase Two as well as other mechanics concepts as judged appropriate. Organization of these interviews within the school program was often difficult. Hence the number of interviews with each of the seven students varies between one (for a student who chose not to study Physics in year 12) and five. All interviewing was done by the teacher/researcher.

Part IV

During the interviews described in Part III, the seven interviewees were also probed for their perceptions of what had prompted any conceptual change which the interviewer identified. In addition some group interviews were conducted with other members of the second cohort involved in Part II of Phase Two. These focussed solely on student perceptions of factors involved in any conceptual change they believed they had experienced, although evidence of conceptual change or the lack of it inevitably emerged.

The sequence, nature and purpose of the data collection for the whole study is summarized in Table 1.

Table 1 about here

We present this table for two reasons: the obvious one of trying to briefly represent the rather extensive set of individual investigations, and also to make another brief reference to researcher conceptual change.

Both Table 1 and the preceding description of successive stages of the investigation inevitably imply an ordered and neat conceptual ...

change in the teacher/researcher. This of course is not the case. Conceptual change is difficult and idiosyncratic, and hence is hard to predict. When the individual is largely responsible for promoting and directing their own conceptual change (as was the case for the teacher/researcher), the timing and nature of any change is even more problematic.

Two specific cases of implied neatness of change in Table 1 which in fact were not the case are mentioned. Phase One Part IV (the extensive interviewing of a high achieving high school graduate) can seem to be the end of a logical sequence which promoted the beginning of change in the teacher/researcher. However, as is shown by a consideration of the year in which investigations took place, this teacher/researcher change was well advanced at the time of this interview. Phase One Part IV was more of the nature of final confirmation of the lack of fruitfulness (in terms of student understanding) in the general style of teaching which was then being used. Phase Two Part I is also less neat than it might appear. Reconceptualizing teaching had been started in the latter part of year 2 of the study (see Table 1). This reconceptualization continued to develop of course. Hence the possible implication that identical restructured teaching existed for both Parts I and II of Phase Two is unreasonable.

Our major purpose in raising these two examples is to emphasize the difficulty of scheduling conceptual change - in adults or school students.

THE ANALYSIS OF DATA

Summarizing data of the nature and quantity involved in this study is both very difficult and very necessary. Unless some form of abbreviating and representing data from open-ended questions and interviews is used, the mass of data in this type of study simply prevents any investigation of patterns and trends. The approach adopted here was developed for this study.

In this approach, student conceptions are considered in two ways: (a) the nature of the student's constructed meaning (conception); (b) given this conception, the degree of understanding of the conception shown by the student. While both of these variables are continuous, and are not independent of each other, for the purposes of data analysis categories for each variable were created. The two variables were then placed orthogonally to generate the matrix shown in Figure 1.

Figure 1 about here

This we call the Constructed Meaning versus Degree of Understanding (CM/U) matrix. Responses of a particular student relevant to a particular concept were judged in terms of the two variables, and the student then placed in a cell of the matrix. This allowed a comparison across time and across students.

Both the development of the CM/U matrix and its use in placing individuals were influenced by a modified Venn diagram produced during the study. This diagram (sometimes termed a Carroll diagram) represents possible conceptual constructions of students, teachers and experts, and is shown in Figure 2.

Figure 2 about here

This symbolic representation of conceptual constructions also influenced the study's conceptualization of assessment of understanding in general.

In using the CM/U matrix our expectation was that the cells on the diagonal E1 - B4 would be more populated, and that extremes such as A1 and E5 would be extremely unlikely possibilities. This was in fact the case, although positions off this diagonal were common in

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this study and are described in other works. We give two examples. Earlier in this paper we described students who had constructed the conception that heavy and light objects have the same weight as a way of accommodating existing and new conceptions. These students would be placed in the D3 and D4 regions (and, in one case, C4), according to the specific detail of their conceptions. Our second example is the description one of us has given (Gunstone, in press) of the quite cohesive and substantial Lamarckian view of evolution which he held for many years of his high school science teaching career. This conception would have been placed in the C4 cell of the matrix.

As a final comment on the CM/U matrix we note that it was a most powerful approach to considering the data of this study. We conject that it will prove a valuable tool for others, but point to the need for explorations of its value both in other contexts and in the hands of other researchers who will have constructed somewhat different meanings for it.

RESULTS AND DISCUSSION

These are presented separately for each part of each phrase. Only rather brief summaries of Phase One results are given, with somewhat greater detail of Phase Two outcomes.

Phase One - Conceptions

Part I

The data show that the years 7 - 10 students held a large number of alternative conceptions involving gravity, acceleration, force, velocity, weight, weighlessness, projectile motion, circular motion and friction. Examples of some of these conceptions include: gravity is related to the presence of an atmosphere; the moon has no gravity (often logically linked to the moon having no atmosphere); artificial gravity can be created by filling a space station with air; force of sun on earth is immense by comparison with force of earth on sun; speed can overcome gravitational forces in circular motion; gravity is

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a form of magnetism; a force acts in the direction of motion on an upwardly thrown ball. Many of these conceptions have been comonly reported (see, for example reviews such as Driver et al., 1985; McDermott, 1984).

When these data were considered as quasi-longitudinal data there was strong evidence of initial and naive physics conceptions changing, but rarely to scientific conceptions. It appears that many students create hybrid conceptual constructions in which scientific conceptions presented by teacher or textbook are accommodated with naive conceptions via the construction of more sophisticated alternative conceptions. In terms of the CM/U matrix year 7 to year 10 tended to be movement from cells E1 - E3 through D1 - D3 to C1 - C3. As many of these students performed well on usual class achievement tests (which tended to emphasize rote learning, formula substitution, etc. in the common way), it may be that their school experiences did little to make fruitful the effort needed by the students to construct scientific conceptions.

Part II

These interviews gave no reason to doubt either the Part I data or the interpretations placed on those data.

Part III

Perspective (a): The nature and frequency of alternative conceptions, and the end of year science achievement grades, of year 10 students were considered in terms of whether or not the year 10 students elected to study physics in year 11. Again the achievement test emphasized "book knowledge", that is the reproduction of knowledge and problem solving approaches given in class notes and text books. The mean year 10 achievement score of the group electing year 11 physics was 8.7% higher than the non-physics group, but there was almost no difference in the frequency of any alternative conceptions across the two groups. This latter result is consistent with the findings of a separate study (Gunstone, 1988).

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Perspective (b): Alternative conceptions of year 11 and 12 students were compared in one area of mechanics, and found to be very similar. When nature and frequency of alternative conceptions of each year level group was compared with achievement scores (again from traditional test forms), very little difference between higher and lower achieving students was found. We interpret this as a strong comment about the efficacy of conventional examinations for probing understanding.

Part IV:

The presence of alternative conceptions in the cognitive structure of this very high achieving student has already been noted. There was often a quite comprehensive internal consistency in these alternative conceptions, for example, the use of centrifugal force to explain apparent weightlessness of orbiting astronauts, artificial gravity in rotating space stations, and so on. The student's lack of scientific conceptions became obvious to him at several points in the interview, but when asked specifically about the problems of understanding these concepts he showed almost no understanding of his own learning.

Phase Two - Conceptual Change

Part I

The first part of Phase Two considered conceptual change in the restructured classroom in a quasi-longitudinal fashion. The same instrument was administered to year 11 and year 12 physics classes at the beginning of one school year. Each of the student responses to each of the 15 gravity-related questions was analyzed and placed on the CM/U matrix. The total of all cell frequencies which resulted, expressed as percentages, is shown by year level in Table 2.

Table 2 about here

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The summary analysis in Table 2 suggests a substantial group shift in conceptions of gravity. Analysis by individual question suggests that the cognitive structures of the year 11 students were characterized by a diverse, complex and complicated set of alternative conceptions. By contrast most of the year 12 students exhibited fundamental and unifying principles applied across contexts.

Three of the questions used in this probe had also been answered by the year 12 students when they were beginning year 11 physics. This occurred as part of a number of informal investigations also undertaken by the teacher/researcher while he was exploring ideas, but not reported in this paper. For these 3 questions, the year 11 performance of the year 12 group was very similar to the year 11 group reported here, as judged by CM/U matrix cell frequencies. This gives further support to the strong suggestion of conceptual change found in the data in Table 2.

Part II

With 6 questions answered by the first group and 17 by the second, each on three occasions, this genuinely longitudinal study generated a large quantity of data. Presenting these data is then a problem. We have chosen to focus on the first of the two groups, and give both a brief summary of all data from this group and a few selected examples to responses to one of the questions. Table 3 shows the summary - the proportions of students exhibiting scientific conceptions (cells B2, B3 or B4 on the CM/U matrix) for each question on each of the three occasions it was answered.

Table 3 about here

This table suggests that substantial conceptual change has occurred in all cases but question 6. Question 6 probes understanding of force exerted on a bouncing steel ball by the surface on which it bounces by asking for comparisons with the normal reaction force <u>mg</u> (Gunstone,

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1987). As previously shown, this is a particularly difficult issue.

We illustrate the detail of these data with a few extracts from student answers and reasons for answers for question 2 - a multiple choice version of Clement's (1982) rocket question. The question is shown in Figure 3.

Figure 3 about here

In each extract the students' multiple choice answer, all or part of their reasoning in support of the answer, and the CM/U classification placed on the reason are given. In some cases the correct answer (E) was accompanied by reasoning indicating an alternative conception, hence the reason, not the answer, was the basis of CM/U classification. As shown in Table 3, the group showed little conceptual change between first and second testing for this question. Only first and third testing data are given in the following examples if the individual showed no change from first to second testing.

Examples of substantial conceptual change on question 2:

(i) 1st testing: Answer "A". "Because the drift force is constant and the thrust is constant, and when point R is reached only the drift force acts". (Categorized C2)

2nd testing: "E". "After Q the rocket has the sideways drift and the thrust down, after R the thrust stops so it has both sideways and downwards drift and so goes at an angle to the vertical". (C3)

3rd testing: "E". "At Q the thrust creates a parabolic path like a projectile, the force then stops at R and the object carries on in a straight line". (B3)

(ii) 1st testing: "B". Forces are constant. Mass without force will move in original direction until another force acts on it. No friction in space". (C2)

3rd testing: "E". "Constant thrust implies constant acceleration. Therefore parabolic path. Continues after R because nothing is there to stop it".(B3)

Example of partial conceptual change on question 2:

1st testing: "A". "It keeps its left-right velocity but adds a down-up velocity at Q. When booster is off it will continue in direction of original velocity as no force is acting to oppose this motion in space". (C2)

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3rd testing: "B". "No force acting so object continues in path indicated by B even when thrust stops". (C3)

Examples of no apparent conceptual change on question 2

(i) 1st testing: "B". "When engines are turned on at Q, thrust is constant causing straight path R. When they are turned off it continues in the same direction as it drifts in space". (C2)

3rd testing: "B". "B represents the best path of the rocket. A, C, D and F cannot be considered because Newton's Law states that an object will continue on its path unless acted on by another force. Therefore does not return to its original path. E is wrong because the force is constant providing a straight path to R". (C2)

(ii) 1st testing: "E". "The rocket still has its horizontal movement and the thrust so the path is curved. After the thrust there are no forces acting, it continues to move along in the same direction". (B3)

3rd testing: "E". "The rocket's thrust creates a parabolic trajectory and when the rocket's motors stop it continues on in the last direction it was travelling at as no other forces". (B4)

The data from the second group are very similar except for one feature. Most conceptual change in that group was either gradual over the three testings or more concentrated in year 11 (first to second testing). This reflects the use of questions of less complexity, although still demonstrably probing of cognitive structure. For example, one set of three questions asked whether the force on a ball thrown in the air is up, zero, or down for when the ball is rising, is at the top of its path, and is falling (Osborne & Freyberg, 1985, p.45). While this set has been widely shown to be a powerful probe of conceptions, it is less complex than, say, the rocket question.

The Part II data from Phase Two of the study reinforce again that the nature of the meaning constructed by any individual can be unexpected, but is influenced by the conceptions brought to an experience. Some students did construct scientific conceptions, but this was usually a slow and difficult process. The existence of data suggesting considerable conceptual change for each group as a whole is taken as evidence that the learning environment in these

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restructured classrooms has achieved to a considerable extent what was planned.

Part III

These interview data from selected members of the second Part II group are even more difficult to present. The transcripts of all interviews comprise over 400 written pages. All we present here are our interpretations of these raw data.

The interpretations we have drawn above from the Part II data were all confirmed. In these interviews attempts were made to be more specific about the nature of any conceptual change and the causes of that change. These attempts were generally successful, but again the nature of the conceptual change was not always as hoped for. In a number of cases students generated different, and usually more sophisticated, alternative conceptions as a result of instruction. Sometimes the same sorts of hybrid conceptualizations referred to in the discussion of Phase One Part I data were formed. This, again, resulted from incorporating aspects of the presented scientific conception into a relatively unchanged alternative conception. For these students it appeared that there was considerably more conceptual confusion after the instruction than was present before. It seems that this hybrid outcome is in part a function of idiosyncratic features of the individual's existing cognitive structure, although other issues such as motivation are no doubt also involved.

On a more positive note there was a quite consistent feature of the instances in which the conceptual change involved movement to a scientific conception. In many cases the crucial factor in this change was the explicitly designed challenge to particular alternative conceptions on which the instruction had focussed. Often perceived fruitfulness for the scientific conception (in the sense of providing a more powerful world view) caused students to change their conceptions. For these students then the restructured classroom was highly ...

successful. What the interview data do not show is why this has occurred with some students and some conceptions but not with other students or other conceptions. Learning is complex and complicated.

Part IV

Aspects of the interviews aimed at exploring students' views of learning were most disturbing. Most of these students had never seriously introspected about their own learning. They had little idea how they, individually, went about learning new knowledge. Many considered that the learning of physics required high intelligence and /or a good memory. This is particularly unfortunate as these two factors are commonly (if erroneously) seen to be beyond the individual's control. These data reinforce the importance of attempting to explicitly teach students about metacognitive and learning issues (e.g. Baird & Mitchell, 1986; Gunstone & Northfield, 1987).

In a more general sense, some ideas about how "everyone" learns were elicited. Most were of the form of committing ideas to memory, but some did talk of testing classroom knowledge against experience and other somewhat constructivist ideas. Regardless of presence of these ideas, physics learning was widely seen as ultimately involving the acceptance of the teacher's version of the science conception, even when this was recognized to be in conflict with the student's conception.

Physics was frequently described as a difficult subject. The most comon reasons for this were a perception of too great an emphasis on mathematics (this in a classroom which had deliberately minimised the mathematics emphasis), and the counter-intuitive nature of many of the concepts to be learned.

CONCLUSIONS

The investigations of student conceptions and conceptual change have generated a number of conclusions. These are listed in point form for the two phases of the study.

...

Phase One: (a) Alternative conceptions exist at all levels of secondary schooling, are prolific, display communalities, and are often complex.

(b) Some students will use different conceptions depending on the context they perceive for a question (which is not the conceptual basis in terms of science).

(c) Students' conceptions will often incorporate aspects of taught science, but this will often be in ways not anticipated by the teacher.

(d) Conceptions of students choosing and not choosing physics at year 11 are little different, although science achievement (and perhaps then propositional knowledge) is greater for those choosing physics.

(e) Conventional instruction seems to have little effect in moving students' conceptions towards comprehensive science conceptions.

Phase Two: (a) Teaching strategies which acknowledge and address implications of alternative conceptions appear to facilitate the generation of meaningful scientific conceptions among many students.

(b) Given (a), conceptual change of any individual is complex, is contextually dependent, and often idiosyncratic and unexpected. Students' existing conceptions are an important element of this context, but not an absolutely determining one. It is not yet possible to confidently predict how an individual will reconstruct meaning after particular experiences, even when great detail of that individual's existing conceptions is known.

(c) In Posner et al.'s (1982) terms, fruitfulness of an internal form (i.e., creating a more powerful and coherent world view) is seen by some students who undergo change to the scientific conception. Most students (including those for whom there is little change or change to another alternative conception) however see fruitfulness ...

only in external forms (i.e., high grades, peer acceptance, etc.). This is unfortunate as those we would see, in the context of this study, as in greatest need of recognition of internal fruitfulness (those not changing to the science conceptions) are those who do not see it.

(d) Students have naive conceptions of learning and conceptual change. They rarely consider their own learning processes and equate success in physics with two factors they see as beyond their control - high intelligence and good memory.

(e) Students see physics as difficult because of an over-emphasis on mathematics (even for a course which has substantially reduced this emphasis) and because of abstract and counter-intuitive concepts.

We conclude by pointing to two broader issues which emerge from the study. The first of these is that there is still much to be uncovered and understood about the detail of what prompts appropriate conceptual change in individuals, and why. This we are continuing to explore. The second broader issue is the other conceptual change generated by the study -- that of the teacher/researcher. This emphasizes the value of the perspectives of Stenhouse (1975) and Schon (1983) to research which seeks to understand and improve practice. Here this value can be seen both in the substantial professional development of the teacher/researcher and in the gener-tion of data and interpretations for others to reflect on.

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TABLE 1

A summary of nature and purpose of data collection

Phase One: Conceptions in mechanics (conventional classrooms)

Part	Year	Year level(s)	Nature of data	Purpose of data
1	1	7,8,9,10	Responses to written probes of understanding	What conceptions do students hold?
11	1	9,10	Interviews probing aspects of Part 1 questions	Are inferences drawn from Part 1 data valid?
111(a)	1→2	10→11(phys) ↘ 11(not phys)	Written probes and science achievement scores, year 10; subject choice, year 11	Do year 11 physics and non-physics students differ in (i) conceptions, (ii) year 10 science grades?
111(b)	2	11,12	POE probes of understanding; physics achievement scores	(i) Do year 11 and 12 physics students differ in alternative conceptions? (ii) Are grades related to alternative conceptions?
1V	3	13 (1st year university)	Extensive interviews with one high achieving student	What is real understanding of a highly successful year 12 graduate?

Phase Two: Conceptual change in mechanics (restructured classrooms)

Part	Year	Year level(s)	Nature of data	Purpose of data
1	3	11,12	Responses to written probes at beginning of year	Does restructured teaching result in conceptual change? (quasi-longitudinal)
11	3→4 & 4→5	11→12	Responses to written probes on a number of occassions over 2 years, two successive cohorts	Does restructured teaching result in conceptual change?
111	4→5	11→12	Individual interviews with selected members of second Part 11 cohort	Are inferences drawn from Part 11 data valid?
1V	4→5	11→12	Individual interviews as for Part 111, and group interviews	What are students' perspectives on the process of any conceptual change?

TABLE 2

CM/U matrix cell frequencies for Phase Two, Part 1 - quasi-longitudinal investigation of conceptual change (all conceptions combined)

Year level	Position on CM/U matrix (%)						Undecipherable/ No response (%)
	Alternative Conceptions			Scientific Conceptions			
	D2	C2	C3	B2	B3	B4	
11 (n = 48)	4.9	20.2	29.7	11.5	22.9	9.9	0.9
12 (n = 26)	-	0.6	8.3	5.5	20.4	64.7	0.5

TABLE 3

Proportion of scientific conceptions exhibited for each question of Phase Two, Part 11 - longitudinal investigation of conceptual change

Question	Proportion of scientific conceptions (%; n=20)		
	First testing (early year 11)	Second testing (end year 11)	Third testing (end year 12)
1	30	65	75
2	15	20	55
3	15	85	90
4	30	65	90
5	30	40	75
6	5	5	25

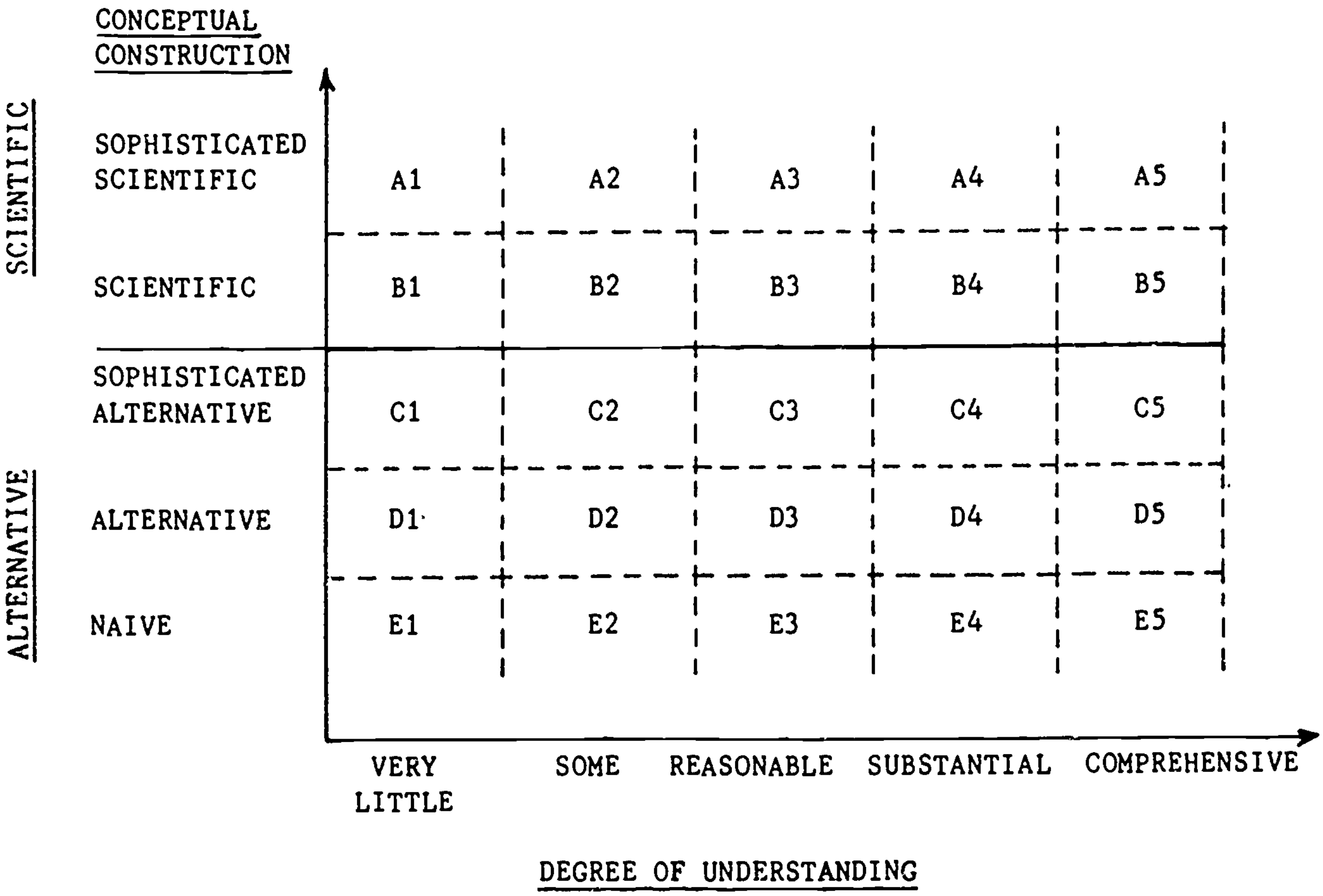


Figure 1: The Constructed Meaning versus Degree of Understanding (CM/U) matrix

CONCEPTUAL CONSTRUCTIONS

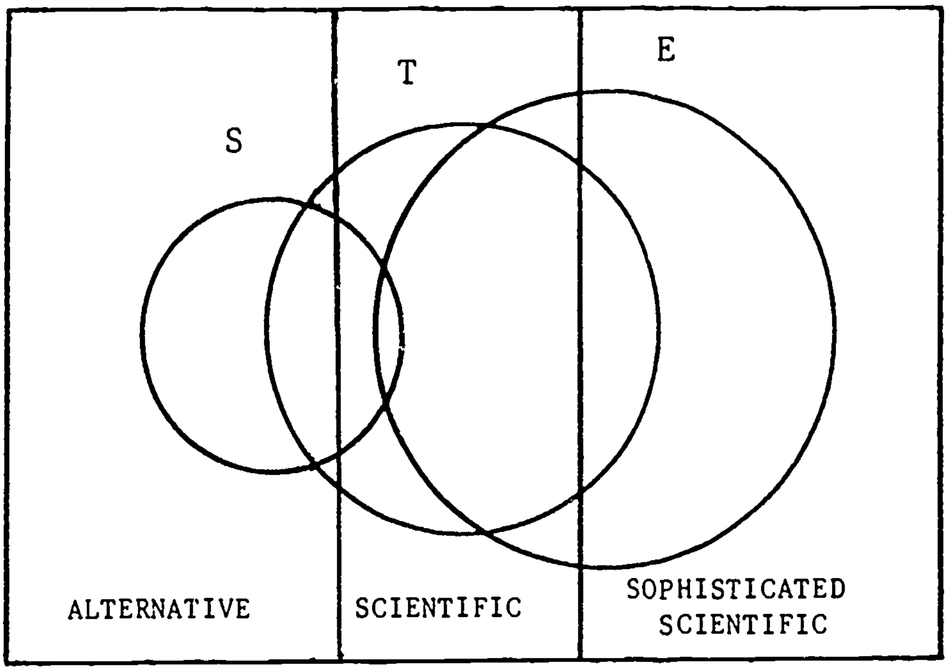
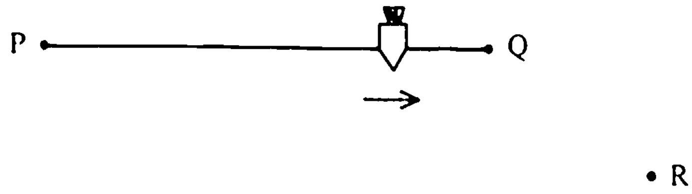


Figure 2: Modified Venn diagram depicting students' (S), teachers' (T) and experts' (E) conceptual constructions

A rocket is drifting sideways from P to Q in outer space. It is not subject to any outside forces.



When the rocket reaches Q, its engine is fired to produce a constant thrust at right angles to PQ. The engine is turned off again when it reaches R.

Question

Which of the following (**A, B, C, D, E, or F**) best represents the path of the rocket?

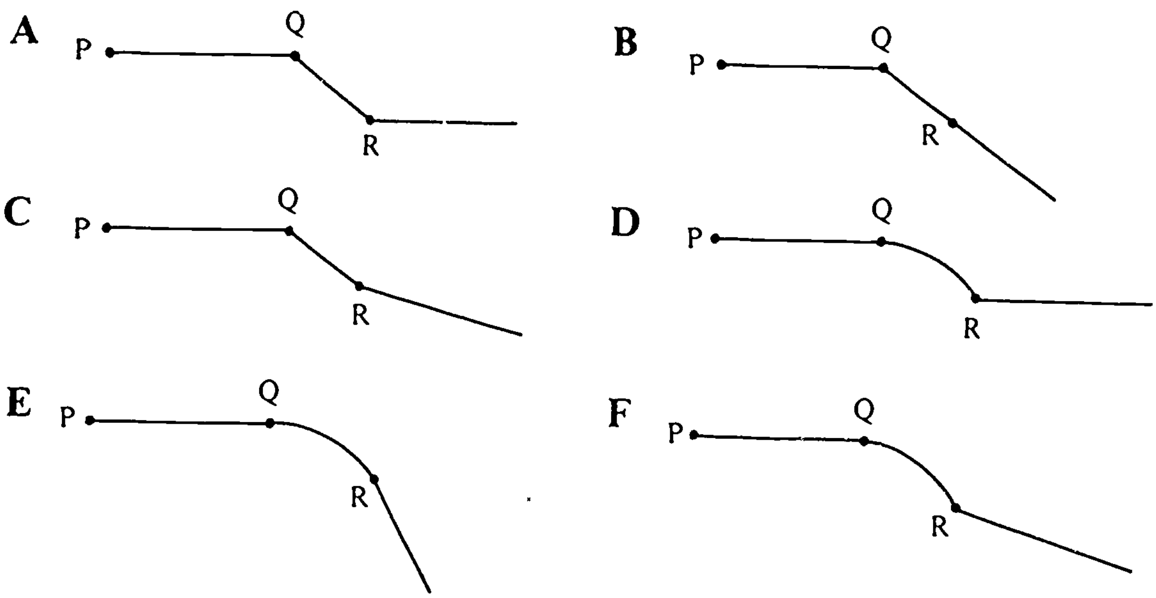


Figure 3: Multiple choice form of Clement's (1982) rocket question